MSFC Thermal Plasma Instrumentation Probing the Topside, Cleft Ionosphere

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Mission and Science Objectives

The Sounding of the Cleft Ion-Fountain Energization Region was a scientific sounding rocket mission conceived to study the prolific outflow of plasma known to emanate from the high-latitude dayside auroral zone. Scientists have known for nearly 10 years that on the order of 10^6 grams per hour of oxygen ions and other ions flow outward from this region of the globe into deeper space. The plasma eventually either becomes entrained in the large-scale magnetospheric convection pattern or escapes the influence of Earth altogether. While the implications of this outflow for the Earth's lower atmosphere or the interplanetary medium and beyond are probably inconsequential (even over long time scales), the same cannot be said regarding their effect on the near-Earth space environment, which may be profoundly influenced by the resultant mass-loading by entrained outflowing plasma. For this reason, the nature and cause of the subject plasma outflow is of great interest to space scientists.

The spacecraft for the Sounding of the Cleft Ion-Fountain Energization Region mission, a Black Brant XII sounding rocket, was optimized to achieve maximum altitude within the geomagnetic cleft region, which generally extends several hours to either side of local magnetic noon in the high-latitude ionosphere and magnetosphere. The scientific payload consisted of alternating-current and direct-current electric-field antenna/receiver sets provided by Cornell University and the University of Bergen (Norway), energetic charged-particle spectrometers provided by the University of New Hampshire, a thermal ion-mass spectrometer (the Scanning Thermal Ion-Composition Spectrometer) provided by MSFC with participation from the University of Texas at Dallas, and the first truly differential and directional thermal electron spectrometer (the Thermal Electron Capped-Hemisphere Spectrometer) ever to be flown in space, which was provided by MSFC with participation from the University of Alabama in Huntsville. Geophysical ground observations were provided on Svalbard, under the vehicle trajectory, by the University of Alaska, the University of Oslo, and University Courses on Svalbard. Ground-based radar diagnostics were provided by the European Incoherent Scatter Radar Facility at Tromso, Norway.

The scientific objective of the mission was to determine why such profuse flows of heavy ionospheric ions emanate from the target region, in spite of the fact that these ions should be strongly gravitationally bound to the Earth. Escape requires energization to roughly 100 times their thermal energy, and—while a number of available energy sources have been identified—the ejection mechanism has not been determined to this point.

MSFC Instrumentation

The Scanning Thermal Ion-Composition Spectrometer was programmed to provide the three-dimensional phase space distribution of hydrogen, helium, and oxygen ions in the energy per charge range from 0.1 to 20 volts. This instrument has flown earlier on several rockets, including members of the highly successful Argon Release for Controlled Studies sounding rocket and the TOPside Probe of the Auroral Zone series.

The Thermal Electron Capped-Hemisphere Spectrometer is a new instrument, developed at MSFC to address the challenging electron energy regime below 5 electron volts. For this instrument, the capped-hemisphere concept of Carlson et al. was brought forth, adding the primary innovation of miniaturizing the sensor to account for the small-scale gyration executed by the target electrons in the Earth's geomagnetic field. The radius of the trajectory curvature of a selected electron within the spectrometer's electrostatic analyzer is only 0.6 centimeter. The instrument was programmed to sweep electron energies from 0.3 up to 60 electron volts, spending most of its time at energies less than 4 electron volts.

Flight Overview

The Sounding of the Cleft Ion-Fountain Energization Region rocket was launched into the pre-noon auroral zone from the Andoya rocket range on the northwestern Norwegian coast, climbed to an apogee of 1,480 kilometers (a NASA sounding rocket record) above the Svalbard Archipelago, and fell to the Earth approximately 750 kilometers short of the geographic North Pole, after 22 minutes of flight. All instrumentation and payload subsystems performed flawlessly throughout the flight. The geophysical target was hit squarely, and a high-quality data set was obtained. Several energetic electron-precipitation events (auroral arcs) were encountered, beginning near apogee and extending into the down leg.

Thermal Plasma Results

Figure 25(a) shows a color-coded display, in energy-time spectrogram format, of the $\log_{10}$ of Thermal Electron Capped-Hemisphere Spectrometer count rates (proportional to electron-energy flux) from one of eight detector channels, in the energy range of 0.3 to 4 electron volts. During the up leg, the energy of peak flux increased from less than 1 to near 2 electron volts, due to an increasingly positive spacecraft potential as the spacecraft moved into regions of lower electron density under solar extreme-ultraviolet photon bombardment. Near 700 seconds flight time, the nature of the measured electron distributions changed as the payload flew into the dayside auroral zone. Intermittent bursts of superthermal electrons observed in the data are seen to correlate with energetic electron precipitation (kiloelectron volts) observed by the University of New Hampshire's energetic particle spectrometers. As the payload proceeded further northward, the thermal electron core became more steady, with peak flux remaining consistently near 1 electron volt.

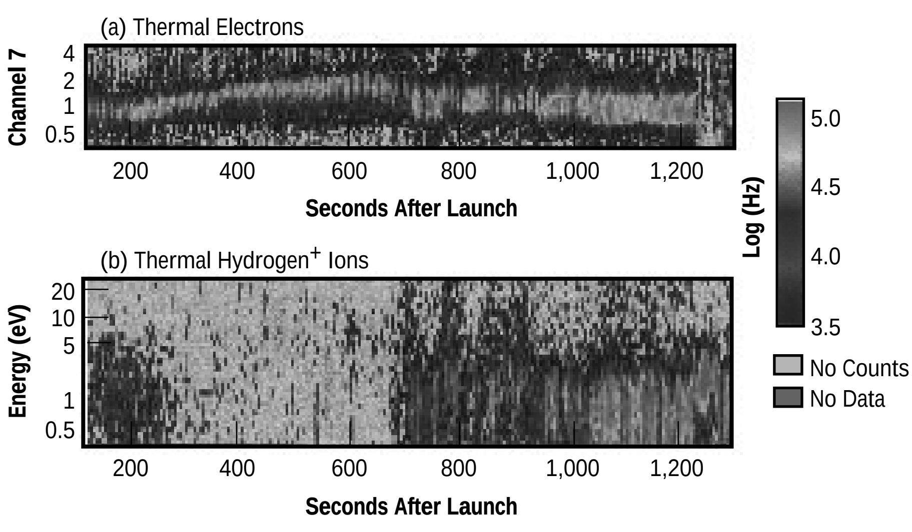

FIGURE 25.—Energy versus time color spectrograms of: (a) thermal electrons observed by the Thermal Electron Capped-Hemisphere Spectrometer; (b) thermal hydrogen ions observed by the Scanning Thermal Ion-Composition Spectrometer during the sounding-rocket flight into the topside, ionospheric cleft on January 25, 1995.

Figure 25(b) shows hydrogen-ion count rates obtained with the Scanning Thermal Ion-Composition Spectrometer in energy-time spectrogram format, similar to that presented in figure 25(a). Here, the energy per charge range extends from 0.25 to 25 volts. The thermal core of hydrogen ions appeared in this data set early on the up leg, but then disappeared out of view due to the repulsive effect of growing positive spacecraft potential. However, at the low-latitude edge of the cleft, ion count rates suddenly returned and heated populations of ionospheric ions were observed, e.g., near 800 seconds after launch. These hydrogen ions and concurrently observed oxygen ions are likely to be flowing outward in response to the local heating, but the full three-dimensional analysis required to confirm this has not yet been completed. Note that between 1,250 and 1,325 seconds after launch, the energy at peak flux of hydrogen ions increased from near 1 to several electron volts. This interval corresponds to an interval illustrated in figure 25(a), where electron counts dropped out. The combined signature is consistent with an increase in negative spacecraft floating potential to nearly 2 volts. The reason for this excursion is unknown at this time, but must be due to variation of in situ plasma properties as the payload drops back through the f-region ionosphere (which will be the subject of future study).

Future Work

The thermal data sets collected will offer a unique view of the topside, cleft ionosphere. Full three-dimensional analysis of these data will permit the evaluation of ion outflows and electron currents or pressure gradients that may be responsible for driving the flows.

The Sounding of the Cleft Ion-Fountain Energization Region thermal electron and ion data sets are the only complete thermal plasma measurements that have ever been obtained in the Earth's ionosphere. Until now, no capability (other than the Thermal Electron Capped-Hemisphere Spectrometer) is known to exist for measuring the differential/ directional, ionospheric, electron-distribution function in the energy ranges below 1 electron volt. Coupled to the thermal ion data, an opportunity exists for the first time to fully address the question of spacecraft charge state and the direct measurement of in situ electric current, including all charge carriers.

Sponsor: Office of Space Science

University Involvement: Cornell University, University of Bergen (Norway), University of New Hampshire, University of Alabama in Huntsville, University of Texas in Dallas, University of Alaska, University of Oslo (Norway), University Courses on Svalbard

Other Involvement: European Incoherent Scatter Radar Facility, Tromso, Norway